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Teaching Chemistry as a Cross-cultural Subject IT & Linguistics

Abstract

The main theme of this paper is the language of chemical formulae rather than the language explaining the chemistry; the focus of our interest is the code used in writing chemical formulae.

This paper describes the nature and scope of the research project started by an out-of-school multidisciplinary team set up in the '90s; the research was conducted in Italy in different socio-cultural contexts in technical as well as classical secondary schools on students 14–16 and 16-18 respectively.

The aim of the work was on the one hand to investigate as to whether or not the teaching-learning process speeds up when students are provided with a previous mnemonic knowledge of chemical formulae and, on the other hand, to test the feasibility of associating old and well-known natural language concepts with chemical concepts.

This work discusses how the communication on chemical topics has been improved by getting the student:

- To master the world language of chemistry.

This task was accomplished through a computer card-game based on the chemistry code.

The software CHICKA (Code Helping In Chemical Knowledge Acquisition) was built on the whole set of chemistry rules for composing inorganic chemical formulae, which was translated into game rules.

The software is articulated in levels and sublevels of increasing difficulty; the cards represent the symbols of the elements and the structure of complex ions; each formula composed appears on the monitor only if it is correct: it will be one of the hundreds formulae of inorganic compounds.

The software does not expect, however, any learning in its users for in the learning-mode the computer has the first hand and the second player is asked to reproduce the computer moves.

But in the tests and tournaments the computer stops being the tutor and becomes the opponent. Here the player can even score higher than the computer because some results are achievable by chance and not only by the competence in chemistry acquired throughout the previous games.

Throughout the game valency, anfoterism, electronegativity and stereochemistry are inadvertently learned.

The game is for any user the world over as no nomenclature is used.
• To identify links between Chemistry and Linguistics by applying to chemistry known natural language concepts such as morphemes and lexemes in order to make students understand the concept of chemical formula long before the explanation of chemical bonds and molecular structures is carried out, and giving teachers some guidelines on practical application to chemistry of concepts such as context, actants and student's encyclopaedia.

• To give some familiar processes a scientific interpretation to be used as vehicle towards theories of physical-chemistry.

The effectiveness of this approach has been demonstrated in drastically diminished gap between teaching and learning; the classroom atmosphere was pleasant and friendly.

Long-lasting learning was verified by using this approach on students who chose Chemistry at university level.

The knowledge of the language of Chemistry acquired before entering the study of chemistry improved the ability to comprehend the subject matter.

Forward

This paper introduces a new method for teaching Chemistry, rather different from the traditional, text-book methods; the proposal is to use this methodology in the first two years of the subject, followed by the application of the traditional methods. This combined approach would ensure a comprehensive knowledge of the subject acquired by the students.

The communication of chemical topics can be improved by getting students to master the world language of chemistry, to identify links between Chemistry and Linguistics, and to give familiar processes a scientific interpretation to be used as a vehicle towards theories of physical-chemistry.

The aim of the work was on the one hand to investigate as to whether or not the teaching-learning process speeds up when students are provided with a previous mnemonic knowledge of chemical formulae and, on the other hand, to test the feasibility of associating old and well known natural language concepts with chemical concepts. The focus of our interest is the code which governs the writing of chemical formulae in their capacity as the language of chemistry since by studying a language we may discover abstract principles that govern its structure and use (Chomsky 1975)\(^5\).

The nature and scope of the research project started by a multidisciplinary team set up in the '90s. The research was conducted in Italy in different socio-cultural contexts in technical as well as humanistic secondary schools on students aged 14–15 and 16-17 y.o. respectively.

The genesis

This work has its genesis in the following consideration: in the contemporary world of technology, the active knowledge of chemistry is of fundamental value. Nevertheless, Chemistry is an unknown science to the general population, and while people are interested in subjects such as environment, food, diet, health, etc., they don’t know that all of these stem
from chemical processes. In addition, some critical remarks on the traditional approach to teaching Chemistry in general education prompted me to attempt to change the overall method.

It is known that the traditional method of teaching Chemistry is focused primarily on the following three areas: the History of Chemistry; the calculations aimed at demonstrating the Laws of Chemistry; and some selected chemical formulae functional to the demonstrations and to develop the capability of solving rather simple mathematical calculations applied to an unknown subject matter. All these skills are very important but in many cases the knowledge gained in this way happens to be quickly forgotten, especially if it is not brought to comparison with every day life. Such teaching practices can result in the fact that too many students tend to consider Chemistry as a possibly interesting subject, but of almost no connection with their general education.

The underlining idea of this work is that these shortcomings can be overcome by associating known concepts of the natural language with the chemical concepts of the processes through which they are presented – of course this must be commensurate with the degree of the linguistic knowledge of students at the corresponding stage of their studies.

Starting from the idea that every micro-language defines patterns and values for reality just as any human language does, the development of students’ scientific language is better achieved by emphasizing and developing structures which already exist in specialized fields of the language. Thanks to the memorization of chemical formulae, students are now ready to consider the formula as a word and apply to it some of the concepts they have assimilated when studying linguistics.

In order to enable students to understand the concept of chemical formulae long before the chemical bond theory and molecular structures are introduced, we have identified in the language some features that can link Chemistry and Linguistics.

The most important implication of this kind of approach is the paramount importance given to the study and knowledge of chemical formulae intended as a language. This brings back the initial key point of contact between the process of teaching and the process of learning chemistry, when students begin to “speak” the Language of Chemistry effortlessly and quickly for the first time.

In order to speed up the language acquisition process, the Language of Chemistry, the chemical symbols and formulae, a computer card game has been developed: CHICKA (Code Helping In Chemical Knowledge Acquisition).

The use of CHICKA develops the students’ ability to work with symbols and pictures by taking advantage of other symbolic or pictorial activities, such as card games, which are already part of their cultural background. It creates a communicative situation between teaching sources and students; favours the interpretation of the chemical formulae while respecting the rules inherent to the chemistry code; and addresses and resolves the first problem common to any communication as it establishes the message.

The proposed method does not seek to undermine the traditional way of teaching chemistry but rather constitutes an important background towards mastering of the chemical terminology in a systematic manner.
The Methodology

This work is structured in two parts. The first part is a theoretical examination of the subject, subdivided in three stages:
- Stage 1 - the links between the Language of Chemistry and Linguistics are identified;
- Stage 2 - an innovative way of presenting common chemical process through macro-linguistics principles is proposed;
- Stage 3 - the development of the software game CHICKA.

The second part consists of the empirical research, subdivided in two stages.
- Stage 1 – CHICKA has been used in the classroom to test the speed of Language Acquisition.
- Stage 2 – Using macro-linguistics concepts to teach chemistry and testing whether the interest in the subject increased.

Part 1, Stage 1 - Identifying links between Chemistry and Linguistics

In this part some analogies between Chemistry and Language have been explored in order to highlight the existing links. These pertain to 6 specific characteristics: Word formation; Inflectional and derivative morphemes; Compounds and compounding; Graphemes, morphemes, lexemes; Open and Closed-Class Words; and Word order.

Word formation

Chemistry language, as every language, has strict rules on word formation: it gives morphological information about the internal structure of formulae. For example, our intuition tells us that the words tree, eat can not be broken down into any meaningful parts. In contrast, the words trees, eating seem to be made up of two parts: the word tree, eat plus an additional element, -s (the ‘plural’) or –ing (the ‘past o present participie’). In the same way our intuition tells us that the chemical word Fe can not be broken down into any meaningful parts. In contrast, the word Fe(s) seems to be made up of two parts: the word Fe plus an additional element (s), which indicates the solid state of aggregation.

Inflectional versus derivative morphemes

‘Tree’, ‘eat’ and ‘Fe’ are called free morphemes; while ‘–s’, ‘-ing’ and ‘(s)’ are called bound morphemes. Two or more morphemes in combination give a complex morpheme (a complex word).

Bound morphemes can be inflectional morphemes as in the above case where they do not change the category of words, or derivative morphemes, as –ize in modernize and –O in FeO that change the category of the words which they are attached to: modern is an adjective and modernize is a verb, Fe is a metal and FeO is a compound. Inflectional morphemes are used to mean particular aspects of the grammatical function of a word or particular states of a compound: in English –er gives smaller, -ing gives singing; in Chemistry H2O followed by (s) means ice (solid water) and NaCl followed by (aq) means a solution of table salt in water. Inflectional and derivational suffixes occur in a certain relative order within words: namely, inflectional suffixes follow derivational suffixes. Thus in modernize-modernizes the
inflectional –s follows the derivational -ize suffix, in FeO(s) the inflectional (s) follows the derivational -O suffix.

**Compounds and compounding**

In English new words can be formed from already existing words to form a compound word. A compound word has semantic and often grammatical characteristics quite different from the two words taken separately. The part of speech of the whole compound is the same as the part of speech of the rightmost member of the compound: the rightmost member of the compound *overdo* is a verb (the verb *do*), therefore the whole compound is also a verb, see figure 1.

<table>
<thead>
<tr>
<th>Overdo</th>
<th>←</th>
<th>over + do</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>PREP</td>
<td>V</td>
</tr>
<tr>
<td>Walkable</td>
<td>←</td>
<td>walk + able</td>
</tr>
<tr>
<td>ADJ</td>
<td>V</td>
<td>ADJ</td>
</tr>
<tr>
<td>Peacefully</td>
<td>←</td>
<td>peace + fully</td>
</tr>
<tr>
<td>ADV</td>
<td>N COUNT</td>
<td>ADV</td>
</tr>
</tbody>
</table>

**Figure 1** Compound words in English

In Chemistry the compound word FeO has both ‘semantic’ and ‘grammatical’ characteristics quite different from the two words taken separately. And considering that the rightmost member of the compound *FeO* is the ion oxide, the whole compound must also be an oxide, as it actually is. FeO(s) is a compound word in its own right, as its properties are not connected to the properties of the single elements *Fe* or *O* (figure 2).

Notice that FeO can be considered either as a compound word made out of the elements *Fe* and *O* - where the two of them have been considered as base morphemes (the free morphemes of figure 12), or as a new word built from the base morpheme *Fe* and the derivational suffix –O, a bound morpheme. This second construction tells the change of category the metal undergoes when it is oxidized from metal to compound while the first one expresses the creation of a new word, the compound word FeO, from the two base morphemes Fe and O taken separately. A careful examination of figure 2 shows the importance of the change that took place in the two of them.
Figure 2  A compound word in Chemistry

Graphemes, morphemes, lexemes

In one of the blast furnace reactions: CO(g) + Fe₃O₄(s) → CO₂(g) + 3FeO(s) the formula 3FeO(s) contains six graphemes 3 Fe O s ( ), one free morpheme 3, one compound lexeme (compound word) FeO and one bound morpheme (s). In the formula 3FeO(s) the morpheme 3 is present only because it is inside an equation in which by definition (just as by convention the main verb of a sentence must agree with its subject) the quantities must be equivalent on both sides. In order to distinguish between different compound words having the same graphemes such as FeO and Fe₃O₄ the chemistry code uses special signs. These signs are subscript numbers. If we were to spell the same formulae using the English code, they would be FeO and FeFeFeOO000. Conversely, if we were to spell the English words to, too and feed, fed using the Chemistry code, they would be written as to, to₂ and fe₂d, fed.

Open versus Closed-Class Words

Examples of open-class words include the English words brother, run, tall, quickly (noun, verbs, adjectives, adverbs) which tend to be quite large and open-ended. That is, an unlimited number of new words can be created and added to these classes. In the same way, we have in Chemistry examples of open-class words that include the words Fe, HNO₃, FeO, CaSO₄ (metals, acids, oxides, salts) which tend to be quite large and open-ended. That is, an unlimited number of new words can be created and added to these classes (see Ca(SO₄) 2H₂O for gypsum or FeO(OH) for rust).

Conversely, closed-class words are those belonging to function classes (such as articles, conjunctions and prepositions). In English the word ‘and’ has the grammatical function to join noun phrases. In Chemistry the word ‘+’ has the grammatical function to join chemical
words under the label of reagents in the context of a chemical reaction; the word ‘→’ corresponds to the English word *towards*, and has the function to signal the direction the chemical reaction points to.

Often what appears to be an individual form in one language actually contains a great number of elements which are ‘similar to words’. For example, in English the form 1-chloro,2-bromo,3n-pentanol steers the meaning which in chemical language should be represented by the formula $ClCH_2CHBrCHOHCH_2CH_3$. Well, is the chemical form just one word? If it is, then it seems to be composed of a series of elements which in English appear as separate words. It seems indeed that the chemical word is rather different from what we normally consider to be a word in English. Yet it is obvious that there are some similarities between the two languages since analogous message elements can be found in both.

Perhaps a better way of observing the linguistic forms of different languages in order to find the wanted analogies would be to look at the use of the notion of ‘message elements’, the morphemes, without having to depend on identifying ‘words’. One can for example disassemble the following English and chemical sentences and list the elements as shown in figure 3.

Readying and studying though broadened the minds of all

\[ Na(s) + H_2O(l) \rightarrow NaOH(aq) + H_2(g) + J \]

![Table of message elements](image)

**Figure 3** The *message elements* in English and in Chemistry

**Word order**

In English the grammatical functions are indicated by the position of each word: the subject in an English sentence typically precedes the verb and the object typically follows it. In Chemistry, if we consider the formula as a sentence, the acidic or basic character of the constituents of the formula are also indicated by word order: the element (or the group of elements) with acidic character typically precedes the element (or group of elements) with basic character, e.g. $(NH_4)_2S$.

**Part 1, Stage 2 - Giving familiar processes a scientific interpretation**

Once the analogies between chemistry and micro-linguistics have been identified, it’s possible to proceed to the second stage: a structured exploration of the subject giving familiar processes a scientific interpretation strictly linked to reality.

The fundamental concept is the identification of the main concepts that govern macro-linguistics in order to apply them to the classroom explanation of many chemical processes.
While bringing these examples to the classroom, it is essential to adhere to the linguistics theory concepts that follow.

**Describing a process**

A chemical sentence should be ‘built’ as far as possible based on students’ background knowledge about how the world is made so that they can make sense of what the text deals with, grounded on what they would normally expect to happen (consistency between theory and reality). A chemical sentence that describes the students’ experience in the picnic context could be the following:

1. Coal or wood + match + air $\rightarrow$ heat

which, using chemical language, becomes:

2. $\text{C(s) or (CH_2O)_n} + \text{J}_1 + \text{O}_2(g) + \text{N}_2(g) \rightarrow \text{J}_2 \quad (J_2 >> J_1)$

However, the reaction found in textbooks to describe the burning of coal is

3. $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$

This reaction, which in itself is correct, does not take into account students’ knowledge about their world - in which for coal or wood to burn there must be a source of ignition (a match), and the process happens in a normal environment where air is present. The textbook reaction contradicts what the student knows however, because it doesn’t mention the need for a match.

This is a clear example of how the gap between theory and reality can be misleading when the plot doesn’t match closely the story: the textbook reaction is perceived by the student as a writing strictly belonging to a chemistry course and not as something that describes a process encountered in real life. Chemistry – from the first approach – becomes in this way only a school subject, rather than an accurate description and often an explanation of the real world. Allowing students to capitalize on their educational background, and build-up their knowledge on it, we obtain not only an accurate description and often an explanation of the real world.

Allowing students to capitalize on their educational background, and build-up their knowledge on it, we obtain not only a keen interest in the subject (due to its connection to reality) but also a comprehensive study from the ground level upwards. The need to spell out every chemical reaction exhaustively from the very first time it’s introduced means that not only strict chemical formulae, as required by stoichiometric calculations, are learnt, but also that thermodynamics are introduced – as an additional and more descriptive layer of reality seen in chemistry language. You can see how the reaction (4) of figure 4 adds to the students’ background knowledge as expressed by reaction (5).

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(4) $\text{C(s) or (CH}_2\text{O)}_n + \text{J}_1 + \text{O}_2(g) + \text{N}_2(g) \rightarrow \text{J}_2 + \text{N}_2(g) + \text{CO}_2(g) + \text{CO}_2(g) + \text{C(s) + H}_2\text{O}_2(g)$</td>
<td>Wood or Coal + Match + Air $\rightarrow$ Heat + Waste</td>
</tr>
<tr>
<td>(5) $\text{Coal or wood + match} \quad 0 + 0 \rightarrow \text{heat} + 0 + 0 + 0 + 0 + 0$</td>
<td>Wood or Coal + Match $\rightarrow$ Heat + Waste</td>
</tr>
</tbody>
</table>

**Figure 4** Picnic reactions

The picnic context gives students the knowledge of a process made by Man to produce heat for his own benefit: a Man-centred process. At this stage, even if it is well known that the burning of wood is an irreversible reaction, we can introduce the concept of chemical
equilibrium - the backbone of chemical industry - in a familiar way by demonstrating that this very reaction can be reversed by simply changing the context.

The photosynthesis process - a Plant-centred process as opposed to the Man-centred process described above – would be the perfect example to describe the reversed reaction of the Picnic process.

The picnic process consumes wood to produce heat to the benefit of Man and pollutes the environment because it also produces (the by-product) carbon dioxide; on the other hand, the main reaction occurring in plants during photosynthesis produces wood to the benefit of the Forest, and by consuming carbon dioxide depollutes the environment (figure 5).

\[
(6) \text{CO}_2(g) + \text{H}_2\text{O}(g) + \text{suns’ radiation} \rightarrow \text{wood} (\text{CH}_2\text{O})_n + \text{O}_2(g)
\]

**Figure 5** The main photosynthesis reaction

The background knowledge of real life can also be used to describe a couple of processes in open systems where at the end of the cycle the starting material is recreated. The classroom discussions that arise from these presentations give the students a developed breath of knowledge (the *encyclopaedia*) that will enable them to understand the concept of chemical equilibrium in closed systems: that reverse reactions can take place in one and the same context.

Through this process students will find the obvious links between the expression they already know and the content. It is essential to consider not just the students’ *encyclopaedia* but also the context within which the chemical reactions occur when determining the most appropriate presentation style. Consequently it is beneficial to examine some of the chief features of the teaching-learning process.

*The Message*

In order to work, the *message* must refer to a *context* that can be easily understood by the receiver, it requires a *code* common to sender and receiver and then a *contact*, a physical channel and a psychological link to establish and maintain the communication (figure 6).

**Figure 6** The Communication

The Students’ *Encyclopaedia* is the understanding about a subject which students have in their mind when approaching anything new - a scientific subject or a material situation in reality. If this encyclopaedia is constantly used by the teacher as a key factor, students will
get used to constantly use the reality they observe as their point of reference. The specific textual competence acquired in this way will enhance their encyclopaedia so that when approaching other specific realities they will be able to develop other skills that in the long run will combine in the general textual competence in science (figure 7).

**Figure 7** Enhancing the Students’ Encyclopaedia

*The Context*

The context is something that must be known by the receiver of the message in order to allow for message transmission. For example, for iron ore to be transformed into iron we must put it into a context: the creation of this context is the blast furnace. Let’s now consider the facts that happen into the blast furnace as a story (tale). Into the blast furnace, Iron Ore (The Subject) must pass certain tests to be able to become Iron (The Object). The Cold (The Opponent) is beaten thanks to the action of Coal (The Helper) and eventually the Hero reaches his goal dictated by a certain Need (The Designator) to the benefit of Man (The Recipient).

This view mirrors the six semantic categories, actants, used in literature to describe the roles of the characters in a story: the helper assists the subject in the trials where he must succeed to obtain the coveted object. This action is rendered difficult by the opponent. The designator establishes the object as the end of desire and communication, while the recipient is the one who benefits from it (figure 8).

**Figure 8** Actants, the six semantic Categories in Literature
The Story and the Plot

We all know that the story (tale) is accessible to everyone, as it uses a type of approach which is temporal and the receiver is in possession of the temporal code. The use of the plot, on the other hand, is allowed only to those who also have textual competence. Therefore, if we introduce a subject concerning chemistry or technology with a plot that doesn’t fit perfectly the story, the only attainable thing is a loss of information due to the noise caused by the unknown code (figure 9).

Figure 9  The Noise preventing Communication

Physical reality can be perceived from various points of view: the very same blast furnace story can be told with different plots depending on the teaching objectives. However, when we present a chemical phenomenon with a plot close to the story, we will be able to easily locate and use those ellipses concerning the way the plot is arranged over time, in order to develop all the wanted sub-stories. These sub-stories allow for the parallel development of the truly scientific plot, the knowledge of particular codes and the resulting application of textual competence (figure 10).

Figure 10  The Story and the Plot

The most intriguing advantage of basing oneself on a General Story, GS, and its several ellipses, is the chance to be able to go back to the GS whenever necessary and interrupt the development of an ellipse for the acquisition of certain basic notions which might be given by yet another ellipse. This itinerary allows for learning phenomena both in terms of their entirety and systematic organization.

Using familiar processes as vehicle towards theories of physical-chemistry

Mundane daily processes can be used to introduce the specific chemical reactions we want to talk about. The ellipses shown in the diagrams suggest theoretical developments and certain basic notions that can be given according to the specific needs. The following two processes are only examples of the many that can be used.

- Frying potatoes  is the Story that allows the teacher to introduce osmosis, to demonstrate that oil never boils, to show the transformation of carbohydrates in coal a
home-made reproduction of the process which thousand years ago led to the formation of the present coal-mines (figure 11).

**Figure 11** The experience of *Frying Potatoes* as General Story

- *Overboiling-an-egg-in-salted-water* is the Story which allows the teacher to speak of thio-proteins and gas diffusion, to demonstrate that hydrogen sulfide is a gas and iron sulfide is a solid, that the white crystals of table salt you put in water when cooking are changed into ions (figure 12).

**Figure 12** The experience of *Boiling-too-much-an-Egg in salted water* as General Story

**Part 1, Stage 3 - Mastering the world language of chemistry**

The third stage of the theoretical excursion consists in finding a valid tool that could enable students to use formulae and the Language of Chemistry with ease. The tool identified as best responding to the goal was a game. From here therefore was born the idea of a computer game built on the whole set of chemistry rules for composing inorganic chemistry formulae, that were then translated into game rules: CHICKA (Code Helping In Chemical Knowledge Acquisition).

The full program consists of two separate games: CHICKA-Basic and CHICKA-Advanced. Both games have many levels of difficulty, and each of them includes sublevels of increasing complexity - conceived so as to add a different chemistry rule each time. Because the
translation is performed by the program, the chemistry rules are perceived by students as game rules.

CHICKA-Basic uses 7 different group-cards. Each group-card represents one of the seven main Groups of the Periodic Table of the Elements, PT, and allows the player to compose binary formulae, between elements belonging to different groups.

CHICKA-Advanced uses about forty element-cards and four different joker-cards. Each element-card represents one of the 35 elements of the seven main Groups, taken separately, and some of the most common transition elements. It allows the player to compose binary formulae such as SO$_2$ between elements belonging to the same group and ternary formulae such as CaSO$_4$ between element-cards and joker-cards. The four joker-cards represent diagrams for the spatial structure presented by complex ions such as carbonate, nitrite, ammonium and the like.

![Image of a game interface](image.png)

**Figure 13** The tetrahedral joker-card with negative combining power

Any formula, composed each time according to the cards dealt to players with each hand, appears on the monitor only if it is correct: it will be one of the hundreds formulae of inorganic compounds. If the player makes the wrong selection, the PT pops up and no score is assigned. Then the computer takes the hand the player has missed.

In learning mode, the software does not expect any previous knowledge in the players: the computer has the first hand and the player must reproduce the computer moves. In the final test of each sublevel, however, and in the tournaments, the computer stops being the tutor and becomes the opponent. The play element is kept with some results being achievable by chance - and not only by the competence in chemistry acquired throughout the previous games - so that the player can score even higher than the computer.

The code of the game is as follows:
• The color  The main valences of the elements are associated with different colors, so that elements of the same valency have the same color. Elements that present a secondary valency have two colors: the color of the group and black. Transition elements are light-blue in their main valency and light-blue/black in one of their most common secondary valences.

• The check-box  The check-box position on the card - left, right or center - is associated with the relative electronegativity value – low (metals), higher (non-metals), or mean - assigned to the element (or the Group). The check-box in the center is given to cards that represent elements that in a compound behave as metals or nonmetals depending on the electronegativity value of the other element. This is the case for hydrogen, H, and many other elements or groups of elements. For example, you can compose the formula Cl₂O where chlorine bears a positive combining-power as well as the formula CaCl₂ where chlorine bears a negative combining-power; and you can also use the tetrahedral joker-card in its capacity as positive group as in the salt (NH₄)₂S as well as negative group as in the salt Al(ClO₄)₃. This is the reason why the tetrahedral joker-card has the check-box centered.

Chemistry is taught here by using images and taking advantage of the natural talent of teenagers for keen observation: the colours of the cards and the position of the check-box on each card are the things to observe, see figure 14.

![Figure 14](image_url)

**Figure 14**  Example of a lucky hand of CHICKA Basic

During the game, the player will also begin to realize that the sequence in which the computer clicks on the cards corresponds to the sequence of the Groups in the PT that pops up any time a wrong move is performed, see figure 3. The game is for any user the world over as no nomenclature is used.
In inorganic chemistry the empirical formula gives essential information, as it gives a fairly complete description of the compound it represents. There is actually a code hidden into the spelling of the formula. Thanks to this code the computer can teach electronegativity, valency, anfoterism and stereochemistry. To briefly illustrate how the game teaches these concepts, an attempt has been made to summarise the relevant game-chemistry rules as follows:

*Electronegativity*

The condition imposed by the first game rule, together with the knowledge of the sign borne by the each Group as indicated in the PT, reveals that elements sitting on the left of the formula bear positive combining-power. With this the player can infer the existence of a ‘certain’ characteristic (electronegativity) that governs the position of the elements in the formula, whose trend proceeds from left to right in the row and bottom up in the column (group) of the PT.

*Valency / combining-power*

With CHICKA the computer imposes the condition that the player selects as many cards of one group as the number of times the element appears in the formula. Thus the player understands that elements can combine to one another in different ratios and, for example, to match one Group IV card one needs two Group VI cards. Should the player’s selection be incorrect, the computer pops up the PT where it is shown that the combining power of the two groups are different: +4 for the Group IV and -2 for the Group VI.

*Anfoterism*

The game imposes as a first rule to *click first on the card that has the check box on the left or more on the left*, the central position of the check-box allows the player to make hydrogen sit on the left of the formula if the other card the player wants to select has the check-box on the right and on the right of the formula if the other card has the check-box on the left.

The possibility for a chemical entity to behave in different ways depending on the context (its position) is called anfoteric behaviour. The anfoteric behaviour of hydrogen is signalled in

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**Figure 15** A curtailed PT of the Elements

![PERIODIC TABLE](image-url)

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the formula by the spelling, while in the game its potential anfoteric behaviour as an element is signalled in the hydrogen-card by the central position of the check-box.

Stereochemistry

To compile formulae made out of more than two elements such as for example potassium, sulfur and oxygen in the salt K₂SO₃ the computer considers the group SO₃ as if it was a single element and puts it in brackets; it then gives it the appropriate combining-power. The group SO₃ (and all other similar groups) is represented graphically by a three-dimensional geometry; in this way students link their background knowledge of geometry to Chemistry, understand the importance of the spatial distribution of the atoms in the molecules and therefore begin to get acquainted with Stereochemistry.

Part 2 – The empirical research: Participants

The socio-cultural background of the students differed considerably among the various schools: a village (Mirano), two industrial towns (Pordenone and Mestre), and a university heritage city (Venice) (Figure 16).

Figure 16 Participants in relation to the socio-cultural context of participants

The types of secondary schools were also different: some had a humanistic focus, and some had a technical focus.

Students’ ages were from 14 to 15 and from 16 to 17.

Part 2, Stage 1 had 250 participant students tested
Part 2, Stage 2 had 220 participant students tested

Stage 2 was introduced to the same students that participated to Stage 1, but at their second year of chemistry studies.

A research limitation consisted in the different syllabus that different schools have about chemistry studies: in some schools Chemistry is taught for one single year, while in other schools it is taught for two consecutive years.

It has therefore not been possible to bring all participants of Stage 1 into Stage 2, and the number of participants to the two Stages does not imply that some students could not be promoted to the second year, but simply reflects those classes that did have two years of chemistry studies in their syllabus.
Part 2, Stage 1 – Using CHICKA to learn the Language of Chemistry

Here the computer game was introduced as a new tool of language acquisition to test if the time required to learn the elements of the PT, the basic formulae and concepts could be reduced when compared to the same ability achieved through traditional, text-book methods. Stage 1 was therefore measured in quantitative terms (length of time occurred to learn). To measure the results, students were given two tests. These were similar in concept to the tests usually given to students at the end of the first term (14 weeks), however in this case the tests were given after only 6 weeks. The first consisted in showing students a list of formulae, among which they had to choose the correct from the incorrect ones. This test was used to verify the ability to recognise a correct chemical formula. The second test consisted in playing with CHICKA in “test mode” (as opposed to the “learning mode” of the game). This test was used to verify the ability to compose chemical formulae starting with the single elements.

Part 2, Stage 2 - Using macro-linguistic concepts to teach chemistry

The teaching method used consists in the teacher’s introduction in the classroom of the process that is to be analyzed, then a visit on site (industries) whenever possible, followed by an open discussion with the students to translate the process described into chemical formulae. The results were measured through constant monitoring of students’ interest and participation.

The Results

Stage 1 results were as follows: 80% of students showed that the speed with which they could learn to read and write chemical formulae increased by 133% (the learning time reduced from c.14 weeks to c. 6 weeks) (figure 17). 5% of students showed the same time reduction, but in relation to reading and recognising the formulae only, and not to composing them. 15% of students did not benefit of this method and reacted in the same way as they did to traditional methods.

![Figure 17 Learning time](image-url)
Stage 2 results were measured in qualitative terms, as the focus was the very interest shown towards the subject, and the quality of learning (high marks versus low marks) compared to the same quality achieved with traditional methods.

Focus on interest and quality was deemed critical because it is essential to the concept of teaching itself, where teachers’ objectives are not only to have students proficient in the class syllabus, but also to have students engaged with the subject at hand, and certainly generally interested in the learning process per se, so that education becomes a life long commitment.

40% of students showed interest in the subject taught, compared to 15% that showed interest when taught in a traditional manner.

Interest was measured by looking at how closely they were following the classes, and how often they participated to class discussions without prompts. The students that showed interest were not (as it is often the case) always corresponding to the top students; that is: in determining the level of interest shown, the marks achieved were not taken in consideration (Figure 20).
When analysing the results through focusing only on the good Chemistry students (marks 7 to 10 in a marks scale that measures from 0 to 10), 66% of the good Chemistry students were also proficient in Maths. This data can be compared with classes where the traditional method was used. In those classes 98% of good Chemistry students were also good Maths students (Figure 20).

The research method therefore expanded the top student base by 33%. Of little statistical significance, but of some interest, is the case of a single student that did not achieve a sufficient level of results in ANY of their subjects and that had to repeat the year: this student did achieve the pass mark (6) in Chemistry.

Conclusion

The creation of a conceptual framework by teaching through multi-faceted issues played a constructive role in developing awareness of the relationship between chemistry and other disciplines and resulted in a significant re-orientation of attitudes by demonstrating the role of chemistry in life with a valid influence on students’ judgment and attitude.

The effectiveness of this approach has been demonstrated by the dramatically diminished gap between teaching and learning. Long lasting learning was verified by using this approach on students who chose Chemistry at University level. The atmosphere in the classroom was
pleasant and friendly. The knowledge of the language of Chemistry acquired before entering the study of chemistry improved the ability to comprehend the subject matter.

In conclusion, the teaching-learning process implemented on the knowledge of the language of chemical formulae to which the content of chemical processes adds, together with a close attention given to matching chemistry processes to the Story of real life, gives a proper understanding of how expression and content are linked in chemistry.

The theoretical and empirical research parts have highlighted the added value of a teaching methodology that closely links the learning of new concepts to the real life of students. If it was possible to achieve this in a subject such as Chemistry – usually considered by students as an abstract theory, far from real life – it is reasonable to hope that the same method applied to other subjects could lead to similar if not even better results. Specifically, what has been developed during Stage 2 of the theoretical part (the attention towards the message, the context, the noise, the Story and the Plot) can be considered generally applicable to all sciences.

This certainly assumes a commitment from teachers to restructure the content of their lessons in order to match the described linguistics concepts to the real life of their own students.

As for Stage 3 of the theoretical part, the game CHICKA, it is necessary to explain that this is only one of the many methods that can be used so that students are encouraged into learning the language of chemistry. Within the scope of this study, we have seen that it is a particularly efficient method but, again, it is not the only one.

The application of linguistic concepts to the teaching of Chemistry is not dependent, nor is a consequence of, the use of this specific game. It was simply shown how, once again, the play element and the physical movement of students enhances their ability to concentrate, memorize and understand a subject.

This concept is valid generally: the “play” element has been included in most teaching methods for a long time, with obvious differences dependent on the age of students – for adult learning just consider role-playing and problem-solving activities.

The added value introduced with CHICKA is that – although not applicable to every subject – it is applicable to every language. It can be used in any country in the world as there are no references to a specific language: the only language taken in consideration is the universal Language of Chemistry.

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Notes

1 Students need not be informed on the game code and rules. They will learn through playing.
2 Gr. ἀμφότερος (amfóteros) = in two ways, the one and the other.
Bibliografía